

EVALUATION OF METHODS FOR USE IN DEVELOPMENT OF SITE-SPECIFIC DISSOLVED OXYGEN CRITERIA FOR THE TERREBONNE BASIN, LOUISIANA

Prepared for

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EXECUTIVE SUMMARY

The Terrebonne Basin covers approximately 1.7 million acres in located in south-central Louisiana and is bordered by the Mississippi River in the north, the Gulf of Mexico to the south, the Atchafalaya Basin in the west and by Bayou Lafourche in the east. Recent monitoring efforts within the Terrebonne Basin have indicated that 32 water bodies do not meet Louisiana's current dissolved oxygen (D.O.) standards.

Louisiana defines D.O. criteria to protect aquatic life at LAC 33:IX.1113.C.3. These criteria are defined as minimum criteria for each of three types of water (fresh water, estuarine waters, and coastal marine waters) with the allowance that "naturally occurring variations below the criterion specified may occur for short periods." These variations reflect such natural phenomena as the reduction in photosynthetic activity and oxygen production by plants during hours of darkness. However, no waste discharge or human activity shall lower the D.O. concentration below the specified minimum." The criteria for each of the three water types are:

- a. Fresh Water. For a diversified population of fresh warmwater biota including sport fish, the D.O. concentration shall be at or above 5 mg/L.
- b. Estuarine Waters. D.O. concentrations in estuarine waters shall not be less than 4 mg/L at any time.
- c. Coastal Marine Waters (including Nearshore Gulf of Mexico). D.O. concentrations in coastal waters shall not be less than 5 mg/L, except when upwellings and other natural phenomena cause this value to be lower.

There is concern that natural conditions within the Terrebonne such as high ambient water temperatures, slow moving and tidally influenced flow of water, and high concentrations of organic matter may cause water bodies within this Basin to exhibit D.O. values below state standards in the absence of anthropogenic stressors. A recently completed study of conditions within the Terrebonne demonstrated that high quality biological communities were observed at many reference sites determined to experience periods of D.O. concentration depressed below the state standards.

The primary objective of this work was to suggest methods for use in development of scientifically defensible site-specific D.O. criteria that account for the naturally-occurring D.O. regime in each of the three regions (fresh, estuarine, marine) defined by Louisiana state standards. These methods may then be used to develop criteria that are protective of aquatic life uses and reflective of natural conditions within the Terrebonne Basin. A secondary objective of this study was to evaluate the biological and water quality data to confirm that sampling sites monitored in a previous EPA study and designated as "least impacted" are appropriate for use as reference conditions in evaluating D.O. conditions in this Basin.

The ambient data used in this work were generated by a recently completed EPA study of conditions within the Terrebonne which collected D.O. and related water quality parameters from 15 sites within three areas (freshwater, mixed salinity, and saltwater) of the Basin between August 2005 and 2006. This study also collected fish community data from each of these sites in August

2006. These data were augmented with D.O. and related water quality data collected by LDEQ at 9 sites in the same three areas of the Basin and fish community data collected at one additional site in the freshwater area.

Fish community values in the freshwater and mixed salinity areas were fairly similar while the composition of the saltwater communities was significantly different. Few meaningful relationships were determined to exist between calculated fish community metrics and various measures of D.O. Therefore, it was determined that there was no reason to conclude that any of the monitoring sites were not “least impacted” or reference conditions for purposes of developing D.O. criteria.

D.O. conditions were fairly similar in the freshwater and mixed salinity areas, while conditions in the saltwater area were significantly different. However, in all sites, the D.O. concentrations decreased markedly during the summer period (May through October) and was higher during the winter season (November through April). In spite of this trend the 10th percentile of the observed daily minimum D.O. values was below applicable criteria in both the freshwater and mixed salinity zones. In fact, the concentration of D.O. was higher during the winter period than current D.O. standards in general.

For the winter period, the 10th percentile of the observed daily minimum D.O. values was below applicable criteria for both freshwater (4.71 mg/L vs 5.0 mg/L) and mixed salinity sites (3.16 mg/L vs 4.0 mg/L). The 10th percentile value (5.59 mg/L) for the saltwater sites was greater than the existing minimum criterion (5.0 mg/L) for saltwater. Based on this analysis, there is potential need for site-specific D.O. criteria for both the freshwater and mixed salinity areas, however the saltwater areas of the Terrebonne Basin appear to be in compliance with existing D.O. criteria. Further evaluation of these data revealed that the upper 95th percentile of the 10th percentile of D.O. observed at freshwater sites during the winter period exceeded the existing criteria (5.63 mg/L vs 5.0 mg/L), while the upper 95th percentile of the 10th percentile value fell below the existing criteria in mixed salinity areas (3.76 mg/L vs 4.0 mg/L). Site-specific D. O. criteria based upon the upper 95th percentile C.L. of the 10th percentile of observed D. O. concentration seem pertinent for the mixed salinity zone (Table E.1).

For the summer, the upper confidence limits on the 10th percentile are less than 5 mg/L for the freshwater and saltwater groups, and less than 4 mg/L for the mixed salinity group. Based on this analysis, the waterbodies are not meeting the existing criterion and site-specific revisions to the minimum criteria would be pertinent for the summer period.

Potential site-specific criteria for the summer period were developed based on natural background conditions in the Terrebonne Basin using the upper 95th percent confidence limit of the 10th percentile of the daily minimum D.O. distribution at these sites for both the summer and winter periods (Table E.1).

Table E.1. Potential daily minimum site-specific D.O. (mg/L) criteria for the summer (May through October) and winter (November through April) periods in the Terrebonne Basin, Louisiana.

Site-specific Criteria Basis	Season	Freshwater (Group 1)	Mixed Salinity (Group 2)	Saltwater (Group 3)
10 th percentile of the observed data	Summer (May – October)	1.48	1.51	2.28
Upper 95% confidence limit on 10 th percentile	Summer (May – October)	1.64	1.75	2.98
10 th percentile of the observed data	Winter (November – April)	4.71	3.16	None
Upper 95% confidence limit on 10 th percentile	Winter (November – April)	None	3.76	None

Alternative criteria were developed for the summer period using the D.O. deficit approach. Using this approach, the 10th percentile D.O. deficit during the summer period at these sites would be 1.59 mg/L (freshwater), 1.49 (mixed salinity), and 2.99 mg/L (saltwater).

Using these approaches, the site-specific D.O. criteria generated in this analysis during the summer period are all fairly similar and would result in site-specific criterion of between 1.5 and 1.6 mg/L for the freshwater area, from 1.5 to 1.8 mg/L for the mixed salinity areas, and between 2.3 and 3.0 mg/L for the saltwater areas. During the winter period the criteria would be 3.76 mg/L for the mixed salinity sites and would use the existing criteria for the freshwater and saltwater sites. Using the upper 95th percentile confidence limit of the 10th percentile of the D.O. distribution is a more conservative approach than simply using the 10th percentile of the D.O. distribution; however it may lead to a greater frequency of criteria exceedances than simply adopting the 10th percentile of the distribution. The D.O. deficit approach is attractive as it accounts for temperature, however implementing such criteria would be more complex and is not known to have been done elsewhere.

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1.0 Introduction

The Terrebonne Basin is located in south-central Louisiana and bordered by the Mississippi River in the north, the Gulf of Mexico to the south, the Atchafalaya Basin in the west and by Bayou Lafourche in the east. The basin encompasses approximately 1.7 million acres which consist of agricultural fields in the northern portion, hardwood forests and swamps in the west, with freshwater, brackish, and salt marshes transitioning to Terrebonne Bay and the Gulf of Mexico in the south (LaCoast, 2008).

Recent monitoring efforts within the Terrebonne Basin have indicated that 32 water bodies do not meet Louisiana's current dissolved oxygen (D.O.) standards. There is concern that natural conditions within the Terrebonne such as high ambient water temperatures, slow moving and tidally influenced flow of water, and high concentrations of organic matter may cause water bodies within this Basin to exhibit D.O. values below state standards in the absence of anthropogenic stressors. A recently completed study of conditions within the Terrebonne demonstrated that high quality biological communities were observed at many reference sites determined to experience periods of D.O. concentration depressed below the state standards (EPA 2007).

Louisiana defines D.O. criteria to protect aquatic life at LAC 33:IX.1113.C.3. These criteria are defined as minimum criteria for each of three types of water (fresh water, estuarine waters, and coastal marine waters). However, the criteria are qualified by the statement, "Naturally occurring variations below the criterion specified may occur for short periods. These variations reflect such natural phenomena as the reduction in photosynthetic activity and oxygen production by plants during hours of darkness. However, no waste discharge or human activity shall lower the D.O. concentration below the specified minimum." The criteria for each of the three water types are:

- a. Fresh Water. For a diversified population of fresh warmwater biota including sport fish, the D.O. concentration shall be at or above 5 mg/L.
- b. Estuarine Waters. D.O. concentrations in estuarine waters shall not be less than 4 mg/L at any time.
- c. Coastal Marine Waters (including Nearshore Gulf of Mexico). D.O. concentrations in coastal waters shall not be less than 5 mg/L, except when upwellings and other natural phenomena cause this value to be lower.

Although the D.O. criterion for each of the water types is presented in a slightly different manner (e.g., "...shall be at or above 5 mg/L...; ...shall not be less than 4 mg/L at any time...; ...shall not be less than 5 mg/L, except when upwellings and other natural phenomena cause this value to be lower."), it appears that Louisiana regulations allow temporally brief deviations below the stated criteria so long as those deviations are the result of natural occurrences.

The primary objective of this work was to suggest methods for use in development of scientifically defensible site-specific D.O. criteria that account for the naturally-occurring D.O. regimes in each of the three regions (fresh, estuarine, marine) identified in EPA (2007) using the monitoring data collected by both EPA in a previous study (EPA 2007) and Louisiana Department of

Environmental Quality (LDEQ). The study should provide methods that can be selected to generate criteria protective of aquatic life uses and reflective of natural conditions within the Terrebonne Basin. The development and adoption of such criteria should ultimately reduce the number of water bodies within this basin that are inappropriately assessed as impaired for dissolved oxygen and therefore, reduce the number of unnecessary Total Maximum Daily Loads (TMDLs) while still maintaining adequate protection of aquatic life in the Terrebonne. A secondary objective of this study was to evaluate the biological and water quality data to confirm that sampling sites monitored in the previous EPA study and designated as “least impacted” are appropriate for use as reference conditions in evaluating D.O. conditions in this Basin.

2.0 Methods and Materials

2.1 Sampling Sites, Data Types, and Data Sources

D.O. data were acquired from monitoring efforts undertaken in the Terrebonne Basin by both the EPA and LDEQ. EPA sampled D.O. concentrations at 15 sites throughout the Basin between August 2005 and August 2006. These 15 sites were selected to represent conditions in freshwater (five sites), saline (five sites), and mixed salinity (five sites) areas of the basin (Table 2.1 and Figure 2.1). The sampling locations were divided into these three groups because Louisiana State D.O. criteria are assigned based on these groupings. Each site was selected based on local land uses (no sites were located near agricultural, industrial, or urban areas) and was designated as representing reference or least impacted conditions within the Basin. D.O. sampling at each site was conducted during four different sampling events using continuous monitoring D.O. probes that were deployed for three to four days at a time and collected data at 15 minute intervals. In addition to D.O., these probes also measured and recorded temperature, conductivity, salinity, pH, and turbidity data. Additional information on the selection process description of these sites is available in the previous report (EPA 2007).

Table 2.1. List of selected sampling locations within the Terrebonne Basin, Louisiana from which D.O. and other data were collected for use in this work. Site locations designations starting with a “C-” are from EPA (2007) and the numbered sites are LDEQ monitoring locations.

Freshwater Sites	Mixed Salinity Sites	Saltwater Sites
C-1	C-6	C-11
C-2	C-7	C-12
C-3	C-8	C-13
C-4	C-9	C-14
C-5	C-10	C-15
2750	3079	3087
998	588	
3082	3111	
3081	3113	

DEQ provided similar continuous monitoring data (e.g., D.O., temperature, conductivity, salinity, pH, and turbidity) for sites reported to be representative of reference conditions in the Terrebonne Basin. LDEQ data were selected for sites that were in close proximity to the 15 sites used by EPA to represent least impacted conditions in the Basin. Based on LDEQ’s assessment of the relationship of their sampling sites to EPA sampling sites, four additional LDEQ monitoring sites were selected for both the freshwater and mixed salinity areas and one additional LDEQ site was selected for the saline portion of the Terrebonne.

The fish communities at each of EPA’s freshwater and mixed sites were sampled one time using electrofishing techniques. In the saline sites, fish community sampling was conducted using

trawls and gill nets. More details are provided in EPA (2007) as to the methods used in collecting fish community data. Fish community data were collected by LDEQ using electrofishing techniques for only one of the freshwater sampling sites which corresponded to EPA's sampling locations. No fish community data were available for the other LDEQ D.O. sites included in this study.

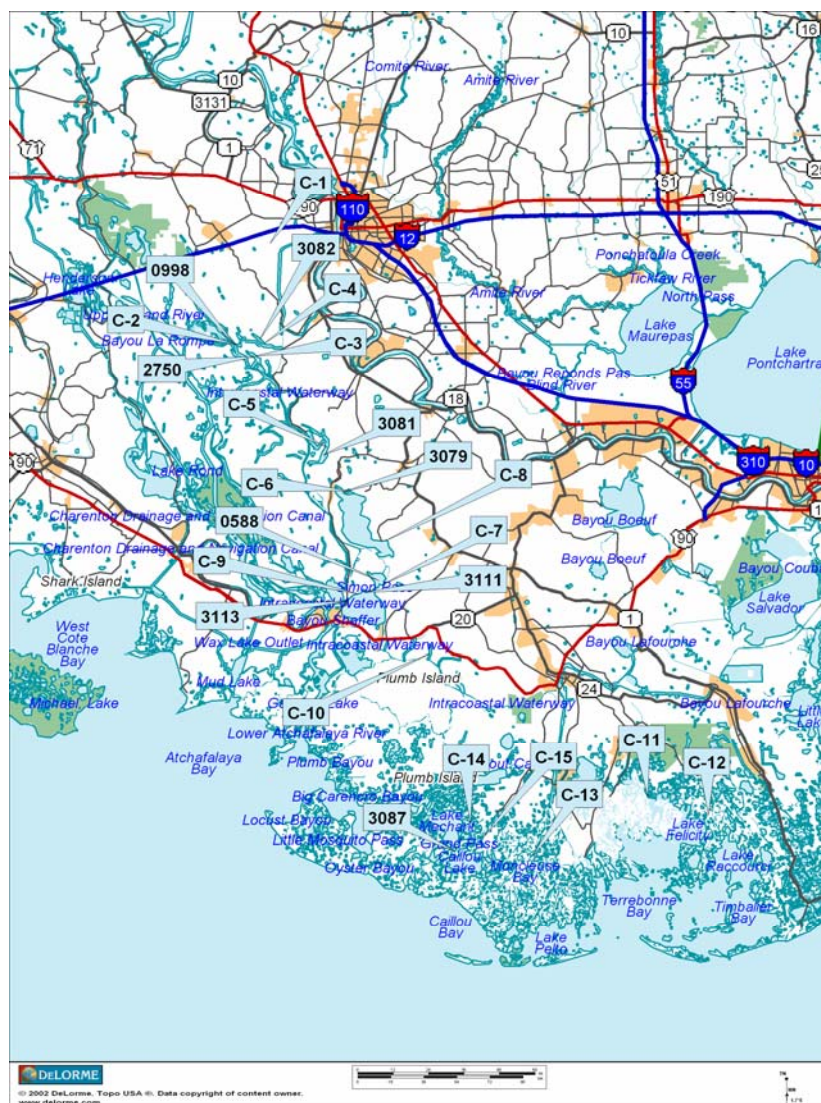


Figure 2.1. Location of sites within the Terrebonne Basin, Louisiana and sampled by LDEQ and EPA and selected for use in this study.

In addition to analyses of abundance and species richness, assemblage composition indices commonly employed in fish assessments were calculated and analyzed. Several indices have been selected for use in this effort based on previous published work demonstrating their reliability (Barbour et al., 1999; Karr and Chu, 1999):

- 1) Number of intolerant species
- 2) Percent tolerant species
- 3) Percent omnivores
- 4) Percent top carnivores

Because no fish community metrics have been developed or calibrated for the Terrebonne Basin or surrounding area, use of these relatively simple and more universal fish metrics is preferred. Tolerance ratings and trophic status (e.g., species defined as top carnivore or omnivores) for fish species were obtained from EPA's Rapid Bioassessment Protocols (Barbour et al. 1999). Although none of these metrics used in evaluating these data are known to be particularly sensitive to dissolved oxygen-related impacts, they allow a more robust evaluation of relative conditions of fish at the various monitoring locations.

The following equations were used in calculating each selected metric:

$$\text{No. Tolerant Species} = \text{sum tolerant species}$$

$$\% \text{ Tolerant Species} = \frac{\text{sum tolerant species}}{\text{sum of total species present}} \times 100$$

$$\% \text{ Omnivores} = \frac{\text{sum omnivorous species}}{\text{sum of total species present}} \times 100$$

$$\% \text{ Top Carnivores} = \frac{\text{sum top carnivorous species}}{\text{sum of total species present}} \times 100$$

Because replicate samples were not collected by either LDEQ or EPA for the sites examined, differences among sites could not be determined with statistical confidence. Therefore, the relative differences observed in the values of these metrics were compared to evaluate whether some sites are less well suited than others to represent "least impacted" conditions within the Terrebonne Basin.

In addition to comparison of metric values, regression analyses were conducted to determine what, if any, relationship exists between fish community metric values and D.O. at the 16 sampling sites. Several statistics of D.O. concentration at each site were used in separate regression analyses, including seasonal minimum recorded, minimum daily average, seasonal daily average, and monthly average. A significant relationship ($p < 0.05$) between dissolved oxygen concentrations and fish community data would suggest that dissolved oxygen concentration may structure the fish community in the basin. Such a result may indicate that observed dissolved oxygen concentrations at some sites are not protective of aquatic life. However, if no significant relationship exists between dissolved oxygen and fish community metric values, then observed dissolved oxygen regimes are apparently unrelated to the fish

assemblage characteristics examined and therefore, it is likely that observed dissolved oxygen concentrations are protective of fish and other aquatic life.

2.2 Data Screening

DO and fish community data collected by EPA (2007) were screened and subjected to quality control/quality assurance (QA/QC) analyses in this study. D.O. data that were noted as suspect or unsuitable for use were excluded from further analysis. Fish community data were screened by EPA and no further data screening processes were applied to those data. LDEQ data were reviewed upon receipt and where noted by LDEQ that data were not suitable for use, those data were excluded from further analysis.

2.3 Criteria Development Method Evaluation Process

In developing water quality criteria (WQC), EPA acknowledged that criteria were designed to be generic and would be expected to be under- or over-protective of the aquatic community in some systems (U.S. EPA 1985). For instance, if the final criteria value is known to be under-protective of an economically or recreationally important species, that value may be adjusted to be protective of the species of concern (e.g., the current U.S. EPA criteria for cyanide were lowered to protect rainbow trout). By the same token, the natural conditions occurring at a given site may indicate an exceedence of applicable WQC, although a high-quality aquatic community exists at that site. In such a case, a modification of the national criteria to reflect these natural conditions may be appropriate and protective of the community at that site.

To account for differences between the national criteria and site-specific conditions, EPA provided guidance for development of site-specific modifications of the water quality criteria (e.g., EPA 1994). Of the three methods outlined for modification of water quality criteria (water-effect ratio development, the recalculation procedure, and resident-species toxicity testing), all are appropriate for generating site-specific criteria for toxic materials. However, D.O. criteria were not generated using EPA methodology for deriving criteria (EPA 1985) and are sometimes referred to as “physiological” criteria (similar to pH and temperature) rather than “toxicity” criteria (for metals and other toxic materials). Because physiological criteria such as D.O. are not based on a toxicity database or even entirely on toxicity data, the existing site-specific criteria generation methodologies are not appropriate for use in generating site-specific D.O. criteria in the Terrebonne.

Site-specific D.O. criteria are most appropriately developed in the Terrebonne under the general statement at LAC 33 IX.1113.C: “Numerical criteria...apply to the specified water bodies...unless unique chemical, physical, and/or biological conditions preclude the attainment of the criteria. In those cases, natural background levels of these conditions may be used to establish site-specific water quality criteria...” Development of site-specific criteria reflective of naturally occurring conditions in the Terrebonne Basin should be protective of the aquatic community and applicable designated uses.

The approach to evaluating potential site-specific criteria development approaches for the Terrebonne basin begins with the general principle that the resulting criteria should be conservative, but not unreasonable. Thus, resulting criteria must ensure that existing uses are

protected, but not be unrealistically restrictive such that reasonably expected and naturally occurring D.O. depressions result in frequent exceedances of the site-specific criteria. The site-specific criterion may be adjusted relative to the existing criterion where indicated by monitoring data. The degree of confidence in the data interpretation is used to determine the degree to which site-specific adjustments are well-supported. The “proof” is obtained from statistical analysis of the monitoring data, in which confidence limits are used to ensure that the results are conservative.

Potential site-specific criteria should be set at levels such that observed conditions worse than those that can reasonably be characterized as natural background should be identified as indicative of impairment, while observed conditions consistent with (or better than) natural background should not result in an impaired listing. The methodology used in developing site specific criteria should incorporate the uncertainty in determining a criteria value, and allow for the conclusion that concentration below the existing criteria are indeed due to natural conditions given the range possible in the sampling.

To achieve these objectives, the analysis focused on the 10th percentile of the D.O. data. To ensure that estimates are conservative, upper confidence limits are placed on the resulting site-specific criteria. As a result, water bodies in which D.O. concentrations are below the existing criteria will only be assessed as unimpaired if there is strong evidence to confirm that they are within the range of natural background conditions. This approach implicitly recognizes the possibility that observed low D.O. concentrations (1) may have some contribution from anthropogenic sources, and (2) may include erroneous low values, attributable to probe fouling for example, or tidal fluxes.

Comparison may also be made to the lower confidence limits on D.O. concentrations because use of such limits minimizes the risk of falsely attributing impairment. Where the lower confidence limit exceeds the existing criteria it is safe to assume that the existing criteria should apply.

2.4 Confidence Limits on Percentiles

The site-specific criteria development approach evaluated here will rely on calculation of the 10th percentile of the distribution of observed D.O. data. A variety of methods exist to calculate confidence limits on percentiles, but many of these rely on assumption of a data distribution form (e.g., Normal distribution). Real world data rarely conform closely to a single distributional form. Due to the uncertainties in using parametric distribution assumptions to estimate confidence intervals on percentiles from small samples, evaluation of the 95% confidence intervals is made using the robust nonparametric method of Conover (1980), which relies on direct evaluation of the order statistics of the observed data via the cumulative distribution function of the binomial distribution. Where sample size is greater than 20, the binomial approximation to this method can be used (Gilbert, 1987).

The binomial approximation method estimates lower (l) and upper (u) order statistics for the true quantile given by the fraction p for a set of data of size n at the $1-\alpha$ confidence level as:

$$l = p(n-1) - Z_{1-\alpha/2} \sqrt{np(1-p)} \text{ and}$$
$$u = p(n-1) + Z_{1-\alpha/2} \sqrt{np(1-p)},$$

where Z is the critical value of the standard normal distribution. The confidence limits are then obtained through interpolation on the available data. For instance, the lower confidence limit corresponds to the interpolated l/n percentile of the data.

2.5 Seasonality

Observed D.O. concentrations typically vary according to time of year. Primarily this reflects the fact that the saturation D.O. concentration varies with water temperature. Thus, a (natural) source that results in a fixed amount of D.O. depletion will result in lower observed D.O. during the summer when water temperature is warmer and the D.O. saturation concentration is lower. In addition, algal activity is generally greater in warmer water and greater available solar radiation is available in summer, resulting in larger diurnal swings in D.O. concentration. Louisiana has typically defined seasonal site-specific D.O. standards based on a summer season (May to October) and a winter season (November to April).

The nonparametric Wilcoxon-Mann-Whitney rank sum test (which is robust against non-normality) is used at a probability value of 0.05 to determine if there is a significant difference in mean values between seasons. The rank-sum test is a non-parametric test of the relationship of central tendency between two independent (non-paired) data sets, with null hypothesis that the populations from which the two data sets derive are the same. Calculation procedures are given by Gilbert (1987) and Helsel and Hirsch (2002), among others, and an exact cumulative small-sample distribution of the test statistic is provided by Dinneen and Blakesley (1973).

2.6 DO Deficit Alternative

As noted above, a fixed oxygen demand will result in differing observed D.O. depending on the water temperature. If seasonal differences are due primarily to temperature, an alternative analysis may be performed in terms of D.O. deficit (the difference between the saturation concentration of D.O. and the observed concentration). This would result in specification of criteria that are a function of water temperature, in which the acceptable D.O. is equal to the saturation D.O. minus the appropriate percentile of the measured D.O. deficit. In contrast to use of direct D.O. measurements, lower confidence limits should be used for the D.O. deficit to maintain a conservative approach. A weakness of this approach is that it does not account for seasonal variability in the algal contribution to the D.O. balance and simultaneous temperature values are needed to implement the D.O. criterion and assess compliance.

3.0 Results and Discussion

3.1 Salinity and DO Characterization Data

3.1.1 Salinity

Although the three classes of sites were nominally divided based on salinity regime, the measured mean salinity values (Figure 3.1) at the freshwater (0.179 ppt) and mixed salinity (0.183 ppt) sites were quite similar, while the salinity of the saltwater sites was much higher (16.07 ppt). This is likely due to the role played by habitat and terrestrial vegetation in selecting monitoring sites and assigning those sites to salinity classes (EPA 2007). These data indicate that the freshwater and mixed salinity sites may be more similar in terms of water quality and potential aquatic communities than initially thought.

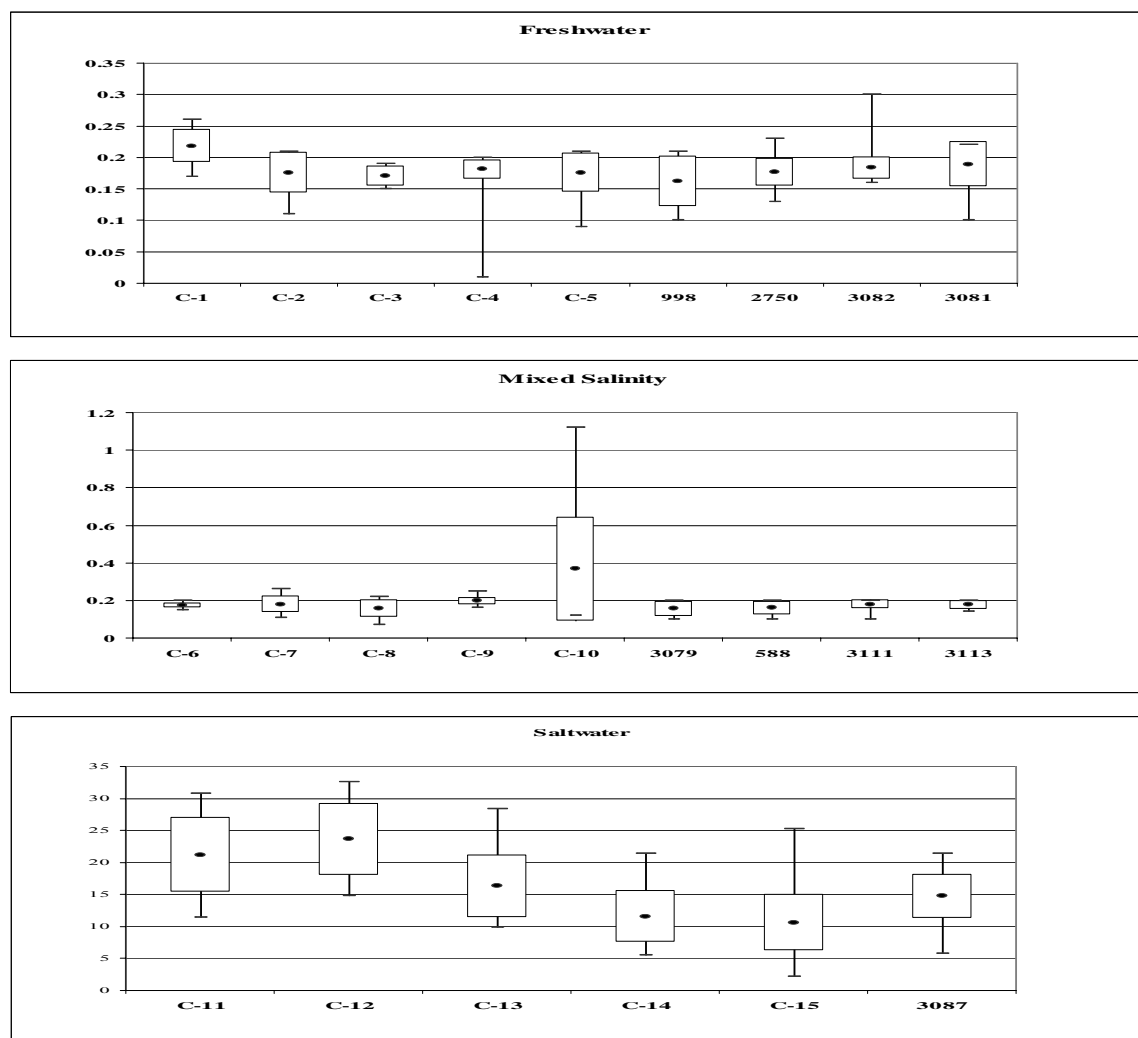


Figure 3.1. Summary of salinity values (ppt) collected from freshwater, mixed salinity, and saltwater sites in the Terrebonne Basin, Louisiana. Each point represents the mean salinity value (ppt), the box represents the mean \pm the standard deviation, and the whiskers represent the maximum and minimum observed values.

3.1.2 Dissolved Oxygen

Continuous monitoring D.O. (and other water quality) data were available for 24 sites within the Terrebonne Basin. The dataset contained a total of 33,107 records, typically obtained at 15 minute intervals over deployments of three days. These monitoring data were divided into freshwater sites (9), mixed salinity sites (9) and saltwater sites (6) according to application of current Louisiana D.O. criteria. Data were collected by both EPA and LDEQ between May 2005 and October 2007. Each of the monitoring sites was selected as representative of least-impacted conditions within the Basin. Prior to analyzing these data, the database was first processed to remove all observations flagged as potentially erroneous in the database (178 records).

Typical results, for station C-1, are shown in Figure 3.2. At this station, four separate deployments were undertaken, at different times of the year. Observed D.O. is frequently less than 5 mg/L, and occasionally less than 3 mg/L.

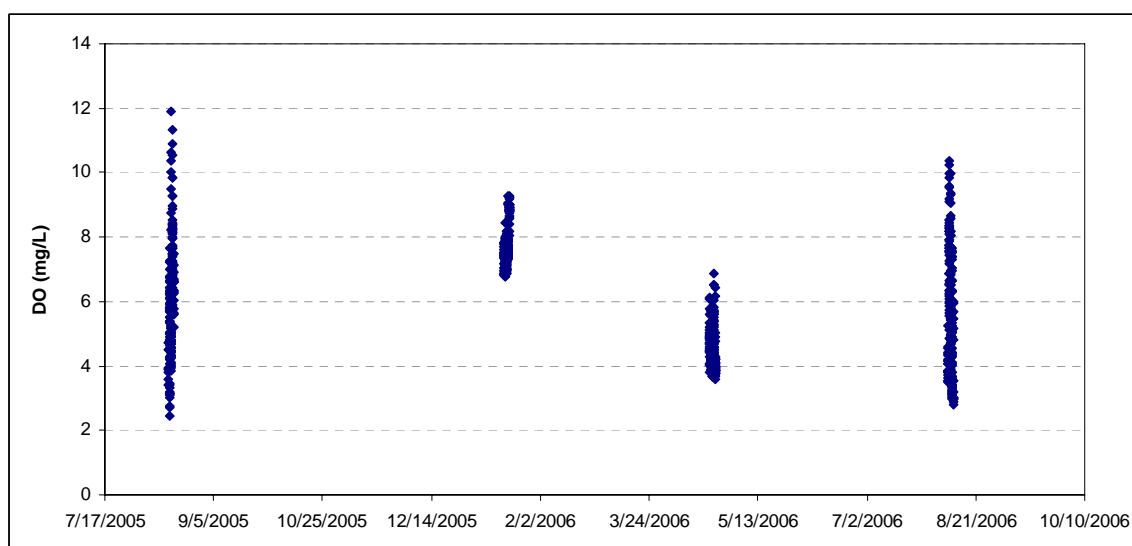


Figure 3.2. Observed dissolved oxygen (D.O.) values at C-1

The trend presented in Figure 3.2 for site C-1 were typical for sites in all three salinity classes in the Terrebonne Basin. Figure 3.3 shows the monthly mean D.O. values collected from all freshwater sites. These data illustrate the seasonal decrease in D.O. observed at all sites, which result in monthly mean values gradually decreasing from well above 8 mg/L in December to below 4 mg/L in July and August. The monthly mean D.O. values measured in the mixed salinity sites (Figure 3.4) exhibited this same trend as well as similar periods and magnitudes of high and low D.O. values.

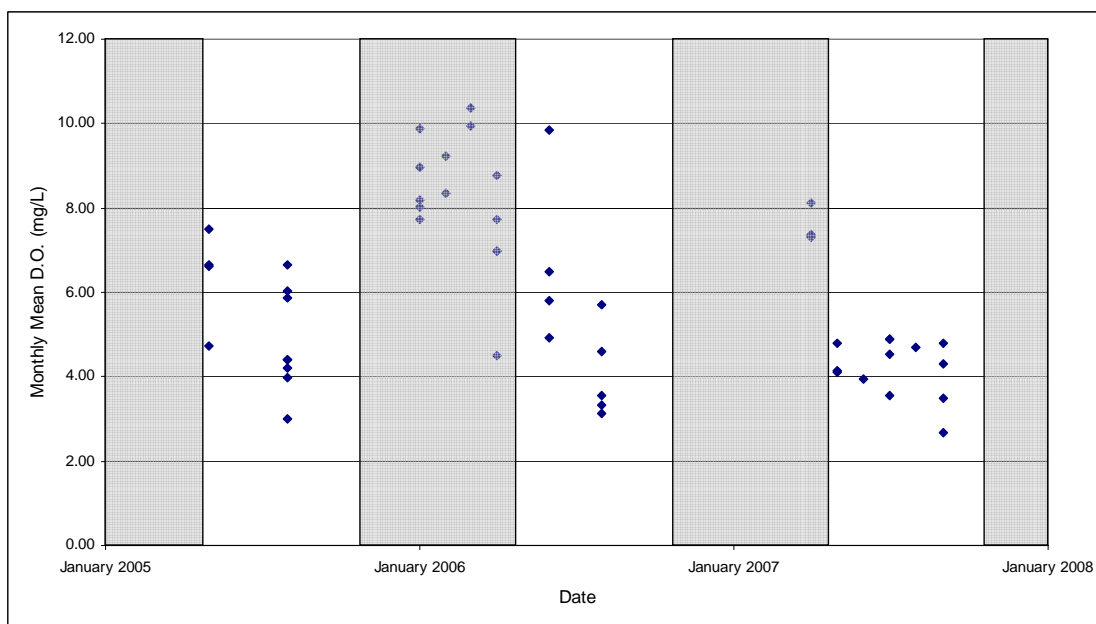


Figure 3.3. Monthly mean dissolved oxygen (D.O.) values collected during multiple sampling events from nine freshwater sites in the Terrebonne Basin, Louisiana between May 2005 and September 2007. Winter season (November through April) is shaded. Summer season (May through October) is not shaded.

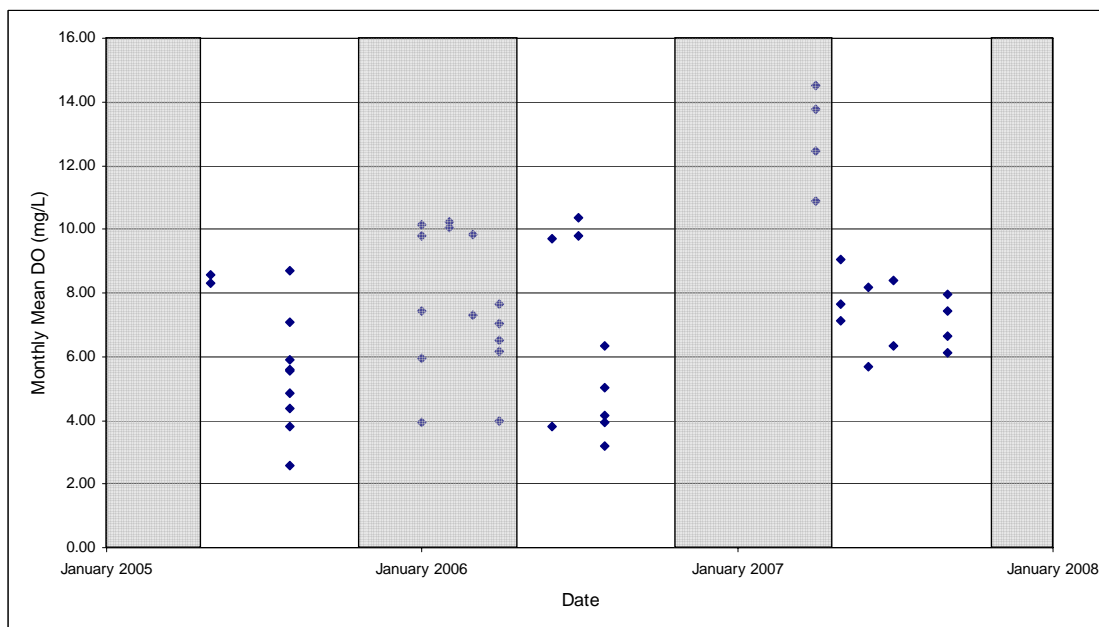


Figure 3.4. Monthly mean dissolved oxygen (D.O.) values collected during multiple sampling events from nine mixed salinity sites in the Terrebonne Basin, Louisiana between May 2005 and September 2007. Winter season (November through April) is shaded. Summer season (May through October) is not shaded.

Similar to the freshwater and mixed salinity sites, the observed monthly mean D.O. at the saltwater locations decreased seasonally (Figure 3.5). However, it does not appear that the monthly mean values fell as low as those observed in the other salinity zones. It is possible that

this observation is simply an artifact of the less extensive monitoring effort undertaken in this zone (e.g., nine sites in either other zone compared to only six in the saltwater zone), but could also be indicative of greater reaeration due to tidal action.

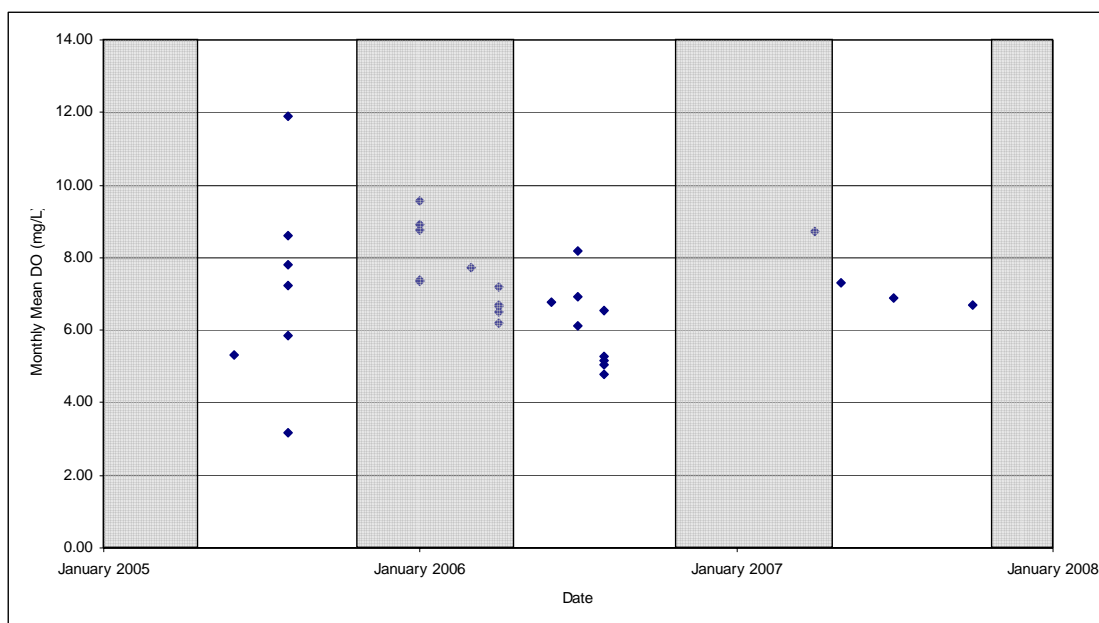


Figure 3.5. Monthly Mean dissolved oxygen (D.O.) values collected during multiple sampling events from six saltwater sites in the Terrebonne Basin, Louisiana between June 2005 and October 2007. Winter season (November through April) is shaded. Summer season (May through October) is not shaded.

As expected, the seasonal low D.O. value was typically lower during the summer season (May through October) than during the winter season (November through April) in all zones (Figures 3.6 through 3.8). In the freshwater sites, the seasonal low D.O. levels typically fell below 3.0 mg/L in the summer and stayed above 4.0 mg/L in the winter (Figure 3.6). Both the summer seasonal and winter seasonal lows appear to have been slightly lower in the mixed salinity zones (Figure 3.7) than in either other zone.

More complete D.O. records for each site and salinity class are presented in Appendix A.

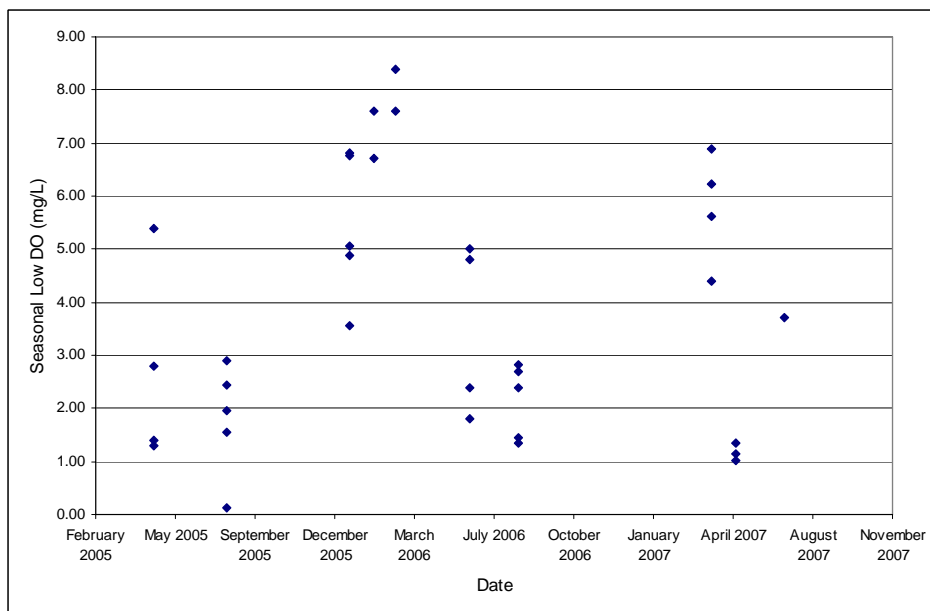


Figure 3.6. Seasonal (May through October and November through April) low dissolved oxygen (D.O.) values collected during multiple sampling events from nine freshwater sites in the Terrebonne Basin, Louisiana between May 2005 and September 2007.

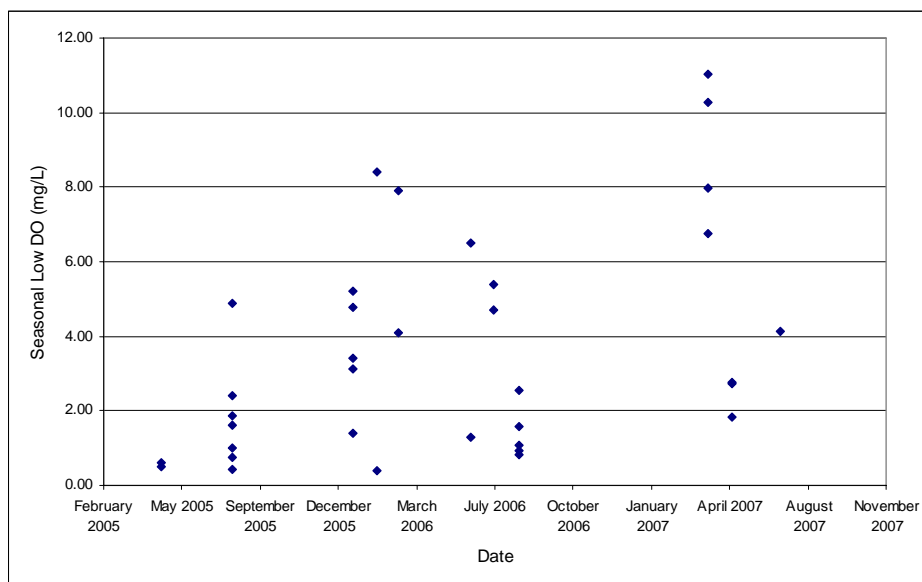


Figure 3.7. Seasonal (May through October and November through April) low dissolved oxygen (D.O.) values collected during multiple sampling events from nine mixed salinity sites in the Terrebonne Basin, Louisiana between May 2005 and September 2007.

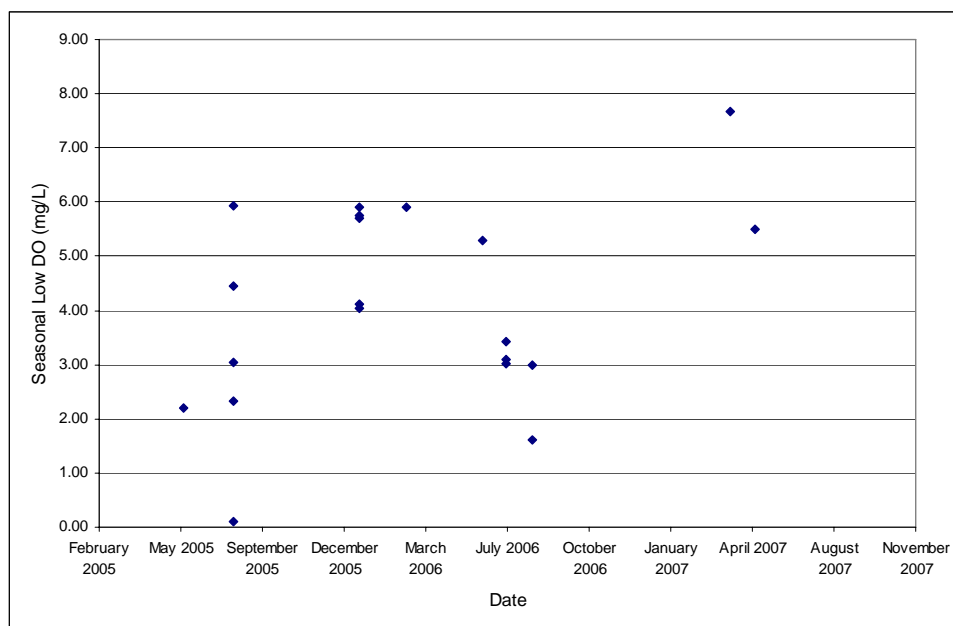


Figure 3.8. Seasonal (May through October and November through April) low dissolved oxygen (D.O.) values collected during multiple sampling events from six saltwater sites in the Terrebonne Basin, Louisiana between June 2005 and October 2007

3.2 Fish Data

Fish community data were collected by EPA contractors at the freshwater and mixed salinity sites C-1 through C-10 using electrofishing equipment between July 31 and August 3, 2006 (Table 3.1). Additional fish community data were collected using electrofishing techniques by LDEQ from site 2750 on March 7, 2006. Fish community data were collected using trawls and gill nets from the five sites representing saline conditions in the Terrebonne Basin between August 7 and 9, 2006 (Table 3.2).

In addition to measures of total abundance and species richness, the number of intolerant species, the percent composition of tolerant species, percent composition of omnivores, and % composition of top carnivores were calculated for the freshwater and mixed salinity sites (Table 3.1). With the exception of site 2750, which was sampled by a different sampling team (LDEQ) at a different time of year, the total abundance (range 74 to 199) and species richness (range 8 to 15) values observed at these sites were fairly similar. Percent tolerant species (range 0.00 to 12.50) and percent omnivores (range 6.67 to 25.00) were also relatively similar for all sites. The final metric, percent top carnivore, was zero for all sites, indicating that none of the fish sampled were considered top carnivores in EPA's rapid bioassessment protocols (Barbour et al., 1999).

Based on the sampling data and these analyses, it appears that fish community characteristics were relatively similar across sites. The exceptional site in this analysis was 2750, which was sampled in March rather than July/August. The difference in sampling season alone could account for observed differences between the fish community at this site and the other sites. Trawl and gill-net samples were collected from each of the five saltwater sites between August 7 and 9, 2006 (Table 3.2). The total abundance of fish at sites C-11 (162) and C-15 (104) were

clearly lower than at the other three sites. However, the vast majority of fish at each of these other three sites was comprised of bay anchovies, a schooling species that is often present in large numbers when it is observed (e.g., Ogburn-Matthews and Allen, 1993). When the abundance of all fish, excluding bay anchovies, is considered, total abundance at these sites ranges from 50 to 134, indicating considerable similarity among sites. Species richness varied from 9 to 20 at these sites, suggesting that during this sampling period there were more species present at sites C-12 and C-13 than the other three sites.

Table 3.1. Summary of fish community metric values collected from freshwater (C-1 to 2750) and mixed salinity (C-6 to C-10) sites.

Site	Sampling Date	Total Abundance	Species Richness	No. Intolerant Species	% Tolerant Species	% Omnivores	% Top Carnivores
C-1	7/31/2006	122	11	1	9.09	18.18	0
C-2	7/31/2006	118	15	1	6.67	13.33	0
C-3	7/31/2006	74	8	0	12.50	25.00	0
C-4	8/3/2006	199	15	1	6.67	13.33	0
C-5	8/2/2006	129	10	0	10.00	20.00	0
2750	3/7/2006	564	23	1	17.39	21.74	0
C-6	8/2/2006	169	12	0	8.33	16.67	0
C-7	8/1/2006	122	15	0	6.67	6.67	0
C-8	8/2/2006	129	15	1	6.67	13.33	0
C-9	8/1/2006	119	8	0	0.00	12.50	0
C-10	8/1/2006	126	11	0	9.09	18.18	0

Table 3.2. Summary of fish community metric values collected from saltwater sites.

Site	Sampling Date	Total Abundance	Species Richness	Abundance of Bay Anchovy	% Abundance as Bay Anchovy
C-11	8/7/2006	162	9	28	17.3
C-12	8/7/2006	1,133	20	1,022	90.2
C-13	8/9/2006	1,161	17	1,063	91.6
C-14	8/8/2006	825	12	758	91.9
C-15	8/8/2006	104	11	54	51.9

As noted, the fish community at each of these sites was sampled only once. Therefore, it is not possible to perform statistical analyses to determine if the observed communities are statistically similar. Fish are quite mobile (e.g., Gelwick et al. 2001; Meador and Kelso, 1989) and given the tidal influence and the diffuse nature of the habitat in the Terrebonne Basin (particularly the mixed salinity and saltwater sites), the fish community data presented here are suitable for use as

a “snap shot” of conditions within the Basin or as part of a larger characterization of fish communities in this system. However, absent dramatic differences in fish community values among sites, it is not possible to use the results from this single sampling event to differentiate between fish communities at these sites.

3.3 Similarities among Fish Communities

In an effort to further evaluate the similarities of the fish communities observed at the sampling sites, nonmetric multiple dimensional scalings (NMDS) was performed on data from the 16 fish samples using Euclidean Distance similarity measure for the ordination. This similarity measure is based primarily on the taxa observed and less so, relative abundance, which for these data appears most appropriate. The NMDS 2-dimensional solution (Figure 3.9) indicates that fish species composition in the saltwater sites is different from that in the freshwater and mixed water sites. A Multi-Response Permutation Procedure (MRPP) was performed to compare site classes according to fish data. Overall, there are significant differences among the three classes (freshwater, mixed salinity, and saltwater) due primarily to the different community present at the saltwater sites ($p < 0.001$). The results also reveal that the communities present in the freshwater and mixed salinity sites are not significantly different ($p = 0.376$). Thus, it appears that the fish communities in the Terrebonne Basin were fairly similar in the freshwater and mixed salinity zones, while the community observed in the saltwater sites was clearly different. The difference between the saltwater sites and other sites is likely due primarily to salinity, but differences in habitat may play a role as well. The similarity of the freshwater and mixed fish assemblages is consistent with the similar salinity regimes observed for these sites (Figure 3.1). This analysis suggests that habitat differences noted between the freshwater and mixed sites may not be a primary factor structuring fish assemblages in this part of the Terrebonne. Results of this analysis indicate that the similarities of the fish communities within the freshwater and mixed sites support the use of data from both types of sites in development of site-specific D.O. criteria based upon natural background conditions. Saltwater sites may need to be broken out separately because of the very different salinity regime (which affects D.O. solubility and saturation) and the different fish assemblage.

3.4 Relationship of Fish Community and Dissolved Oxygen

Of 98 simple linear regression analyses evaluating the relationship between various fish community parameters and various measures of D.O. in the Terrebonne Basin, only four of these relationships were determined to have a slope that suggested negative impacts to the fish community related to D.O. concentration and an r^2 value above 0.5 (Appendix B, Tables B.1, B.2, B.3, and B.4). A meaningful slope was defined as a negative slope for a relationship between either fish abundance or species richness and D.O. concentrations (e.g., as D.O. decreased, so did the corresponding fish metric) or a positive slope between % tolerant species or % omnivore and D.O. concentrations (e.g., as D.O. decreased, the corresponding fish metric increased). An r^2 value of 0.5 was used as this value indicated that D.O. explained 50% or more of the observed variation in fish community values.

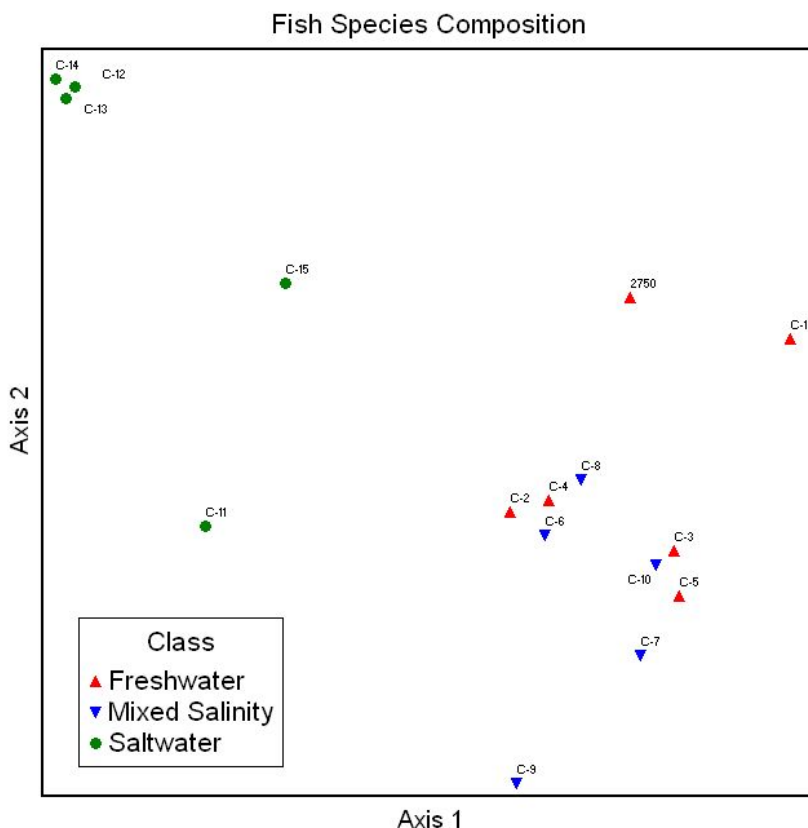


Figure 3.9. Ordination plot illustrating the similarity in species composition among the 16 sampling sites in the Terrebonne Basin, Louisiana. Sites closer together in ordination space indicate greater similarity in fish assemblage characteristics.

Table 3.3 summarizes the four significant relationships observed. The relationship between 2005 summer low D.O. and total fish abundance was no longer significant ($p = 0.9$, $r^2 = 0.0037$) once data from Site 2750 were removed from the dataset. Because the data from this site were collected during a different season (March 2006 vs. August 2006), such exclusion from analysis is probably appropriate.

Table 3.3. Summary of results of simple linear regression analyses showing relationships with a slope indicating negative effects related to D.O. concentration, an r^2 value exceeding 0.5 and a P value less than 0.05.

Parameters Regressed		Group	Slope	r^2	P Value
2005 Summer Low DO	Total Abundance	Freshwater	0.0078	0.6609	0.0492
Lowest Daily Mean DO	% Tolerant Species	Mixed Salinity	-0.1969	0.8407	0.0284
Mean DO August 2006	% Tolerant Species	Mixed Salinity	-0.3075	0.8474	0.0266
2006 Summer Low DO	% Tolerant Species	Mixed Salinity	-0.1860	0.8832	0.0176

The three remaining significant relationships for the mixed salinity sites appear to describe legitimate relationships between D.O. and fish community condition. This is supported by the fact that the fish data were collected in early August 2006 and two of the three D.O. parameters

determined to be significantly related to these fish metrics were calculated for August 2006 and summer 2006. However, none of the other relationships between fish community metrics and D.O. appear to be meaningful for the mixed salinity sites. It is possible that these analyses have identified a natural condition in which species less tolerant of environmental stresses (e.g., low D.O., higher temperature and salinity) move out of the brackish areas and into fresh waters during the summer. Such a migration is possibly analogous to those described by Gelwick et al. (2001) that take place in brackish waters of a Texas Gulf coastal wetland.

The majority (94 of 98 or 96%) of the relationships evaluated between fish community metrics and D.O. values were not found to be meaningful, suggesting that D.O. is generally not acting to structure the fish community in the Terrebonne Basin. Although a very few (4%) meaningful relationships were observed, this would be expected by chance alone given a p value of 0.05 or 5% in these analyses. Furthermore, it does not appear that the observed low concentrations of D.O. have been shown to have a negative effect on the overall fish community, or even at a single site. However, caution should be taken in that these conclusions are based on data collected during a single sampling event. It is possible that more extensive and frequent sampling could yield a different picture of the interrelationship between D.O. and fish communities.

Based on the above analysis, it appears that all sites sampled may be indicative of least impaired fish conditions and data from these sites should be considered appropriate for use in characterizing the natural condition within the freshwater and mixed salinity regions of the Terrebonne Basin.

4.0 Evaluation of Methods for Use in Criteria Development

4.1 Characterization of Dissolved Oxygen Data

After removing erroneous data from the database, 33,107 records remained to be used in characterizing the D.O. conditions within the Terrebonne Basin. To aid in analysis, the following steps were taken:

- For each record, the saturation D.O. concentration was calculated as a function of temperature and salinity (converted to chlorinity) using the equation recommended in *Standard Methods* (APHA et al. 1995). Calculations were made at standard pressure (1000 mb), as atmospheric pressure can be assumed to be that of sea-level.
- D.O. deficit was calculated for each record as the difference between saturation D.O. and observed D.O.
- Data for D.O. were summarized by the daily average and minimum value; data for D.O. deficit were summarized by the daily average and maximum value.

This procedure yielded two data sets of 473 records. Summary statistics for D.O. from this revised dataset are summarized in Table 4.1.

Table. 4.1. Summary statistics of daily average and minimum D.O. (mg/L) values for the Terrebonne Basin, Louisiana.

Group	Daily Average D.O. (mg/L)		Daily Minimum D.O. (mg/L)	
	Average	Median	Average	Minimum
Freshwater	6.04	5.69	4.54	0.13
Mixed Salinity	7.18	7.00	4.99	0.40
Saltwater	7.06	7.01	5.49	0.09

The distribution of D.O. data is summarized via box and whisker plots in Figure 4.1, in which the box represents the interquartile range and the notch represents the median and its 95% confidence interval. Distributions are similar among the three groups, although there appears to be a trend of increasing D.O. mean and minimum with increasing salinity as discussed in Section 3.0. The mean of the daily minimum for saltwater sites was significantly greater than the mean of the daily minimum at the freshwater sites on a Scheffe multiple comparison test at the 95 percent confidence level.

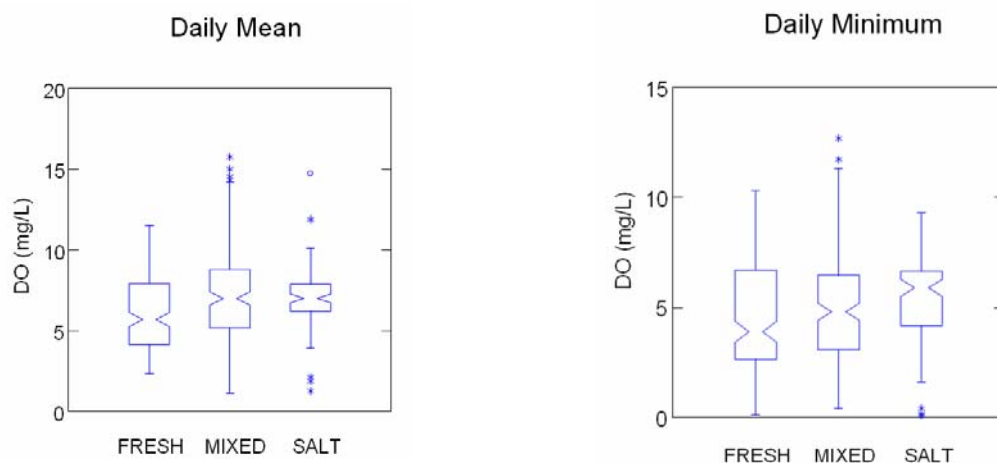


Figure 4.1. Box plots of D.O. (mg/L) daily mean and daily minimum values from the Terrebonne Basin, Louisiana.

While all sites were selected as representative of minimally disturbed or natural conditions, there is noticeable variability between D.O. values at sites within individual groups. This is best evaluated in terms of D.O. deficit, which removes the influence of differences in temperature and salinity. Basic statistics for daily maximum D.O. deficit are provided in Table 4.2.

Table 4.2. Summary statistics for daily maximum D.O. (mg/L) deficit from sampling sites within the Terrebonne Basin, Louisiana.

Group	Average	Median	Maximum	Minimum
Freshwater	3.72	3.83	7.22	-1.24
Mixed Salinity	3.21	3.43	8.49	-3.95
Saltwater	2.06	1.64	6.88	2.06

There is a general trend that the daily maximum D.O. deficit increases (and thus the minimum D.O. concentration decreases) with lower salt content. D.O. deficit is often less than zero, indicating supersaturation likely caused by algal production. The extent to which algal densities in these waters are truly “naturally occurring”, rather than attributable to anthropogenic nutrient loads, is not known.

Distributions of the daily maximum D.O. deficit are summarized for the three groups in Figure 4.2. For freshwater sites, there is significant overlap in the distributions among sites, suggesting consistency, although the medians differ. The distributions at the saltwater sites also generally overlap, although there is greater variability among sites. The mixed salinity sites present a wider range (perhaps reflecting variations in salinity), but generally cover a continuum of conditions.

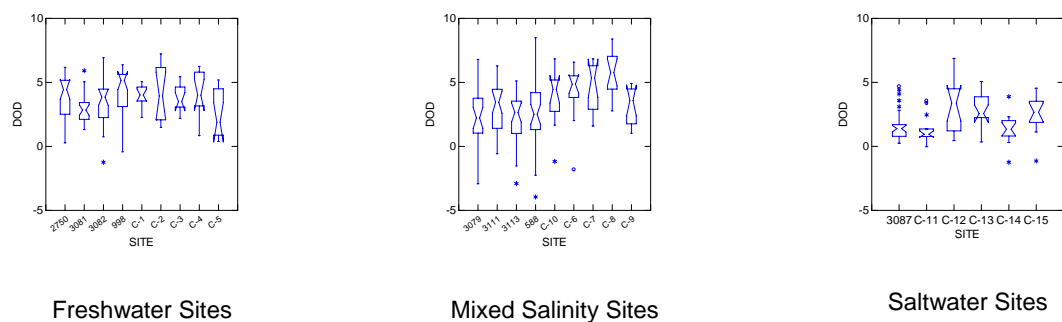


Figure 4.2. Distribution of daily maximum D.O. deficit (DOD) as mg/L among sites in the Terrebonne Basin, Louisiana.

4.2 Minimum D.O. Criteria

Louisiana's D.O. criteria are applied as minimum values to be violated only during brief excursions below criteria limits due to natural events. Therefore, compliance with these criteria were assessed based on minimum observed values. To differentiate between D.O. conditions in the winter (November-April) and summer (May-October) periods the Wilcoxon-Mann-Whitney rank sum test was applied to each group of minimum D.O. data. For all three groups, the null hypothesis that the two data subsets (winter and summer seasons) derive from the same population was rejected at the $\alpha=0.05$ level. Therefore, separate results were developed for the summer and winter seasons.

As described in Section 2, potential approaches to develop site-specific revisions to the minimum criteria were evaluated by estimating the non-parametric upper 95th percentile confidence limit on the 10th percentile of the data. Results are shown in Table 4.3, where they are compared to the 10th percentile of the observed daily minimum DO data.

Table 4.3. Summary of daily minimum D.O. evaluation for the winter season (November through April) for sites in the Terrebonne Basin, Louisiana.

	Freshwater	Mixed Salinity	Saltwater
Sample count (days)	65	63	44
Upper 95% confidence limit on 10 th percentile	5.63	3.76	5.87
10 th percentile of the observed data	4.71	3.16	5.59

As intended, the confidence limit approach shifts the observed 10th percentile upward to account for uncertainty in the sample estimate. For the winter period, the resulting 10th percentile values fall below 5.0 mg/L in freshwater and below 4.0 mg/L in mixed salinity waters. However, the values at the saltwater sites were observed to contain greater than 5.0 mg/L. These results indicate that development of site-specific criteria based on natural background conditions may be

warranted for freshwater and mixed salinity sites. However, the saltwater sites are in compliance with the existing criteria. It is possible that the existing criteria in saltwater areas may be raised based on these analyses of natural background conditions.

Because the upper 95th percentile of the 10th percentile of the observed D.O. data in the freshwater sites is in excess of the existing Louisiana state D.O. criteria (5.63 mg/L vs. 5.0 mg/L), a site-specific criteria based upon natural background conditions may not be necessary for these sites during the winter (November to April) period using this approach. Continued application of the existing Louisiana state standard of 5.0 mg/L may be appropriate for these waters. However, if the 10th percentile approach without application of the 95th percentile were used, a potential site-specific criterion for the freshwater sites would be 4.71 mg/L.

Of the three zones, only the D.O. data collected from the mixed salinity waters appear to support development of a lowered site-specific criteria based upon the upper 95th percentile of the 10th percentile of observed data. Based on these analyses the upper 95th percentile of the 10th percentile distribution of the observed data of 3.76 mg/L would be applied as the site-specific criteria based upon natural background conditions during the winter period.

Results for the summer period (May to October) are provided in Table 4.4. For the summer, the upper confidence limits on the 10th percentile are well below the applicable D.O. criteria of both 5.0 mg/L (fresh water and saline sites) and 4.0 mg/L (mixed salinity waters). Therefore, site-specific revisions to the minimum criteria appear to be appropriate for all sites for the summer period.

Based on an approach of using the upper 95th percentile confidence limit of the 10th percentile of the distribution of the D.O. data as the site-specific criterion, the site-specific D.O. criteria would be minimum values of 1.6 mg/L for the freshwater area, 1.8 mg/L for the mixed salinity areas, and 3.0 for the saltwater areas (Table 4.4). An alternative, and less conservative approach, would be to simply use the 10th percentile distribution of the D.O. data as the criteria. Such an approach would yield suggested site-specific minimum D.O. criteria of 1.5 mg/L for the freshwater and mixed salinity areas and 2.3 for the saltwater areas (Table 4.4).

Table 4.4. Summary of daily minimum D.O. (mg/L) evaluation for the summer period (May through October) in the Terrebonne Basin, Louisiana during the summer period (May through October).

	Freshwater	Mixed Salinity)	Saltwater
Sample count (days)	117	128	56
Upper 95% confidence limit on 10 th percentile	1.64	1.75	2.98
10 th percentile of the observed data	1.48	1.51	2.28

4.3 Alternative Criteria Development Approach

In addition to setting D.O. criteria as absolute D.O. concentrations in the above analyses, as an alternative, the data were also analyzed in terms of D.O. deficit. Evaluating conditions and criteria in terms of D.O. deficit automatically corrects the resulting D.O. concentration for temporal and site-specific variations in temperature. Because salinity has a relatively small effect on saturation given the range of salinity observed in each class of sites, calculations for each group were made at the respective average salinity values discussed in Section 3.0. Lower 95th percentile confidence limits on the median and 90th percentile of D.O. deficit are presented in Table 4.5.

Table 4.5. Summary of confidence limits on calculated median D.O. deficit (mg/L) and on the 90th percentile D.O. deficit (mg/L) for sites within the Terrebonne Basin, Louisiana.

	Freshwater	Mixed Salinity	Saltwater
Lower 95 th percentile confidence limit on median	1.956	0.684	0.040
Lower 95 th percentile confidence limit on 90 th percentile	5.626	5.719	3.630

The following three Figures (4.3 – 4.5), describe both the median and 10th percentile D.O. values as a function of temperature.

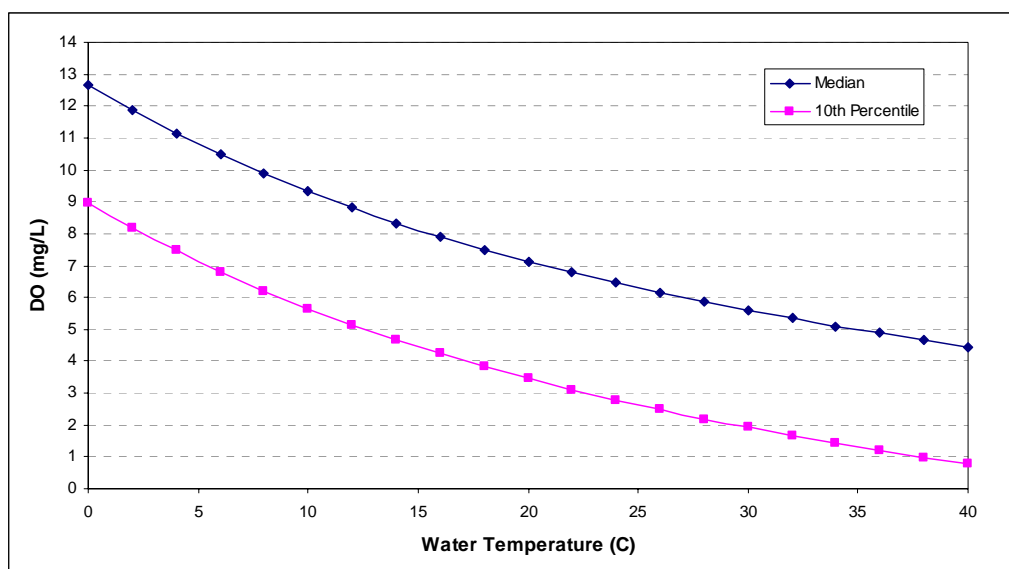


Figure 4.3. D.O. criterion curve based on 95% upper confidence limits on observed D.O. deficit, freshwater sites within the Terrebonne Basin, Louisiana.

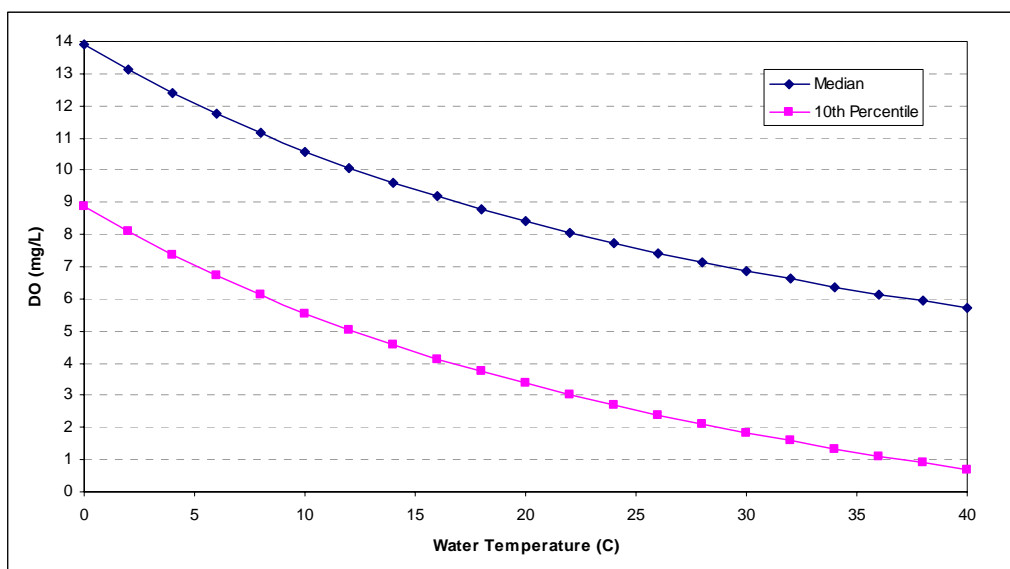


Figure 4.4. D.O. criterion curve based on 95% upper confidence limits on observed D.O. deficit, mixed salinity sites within the Terrebonne Basin, Louisiana.

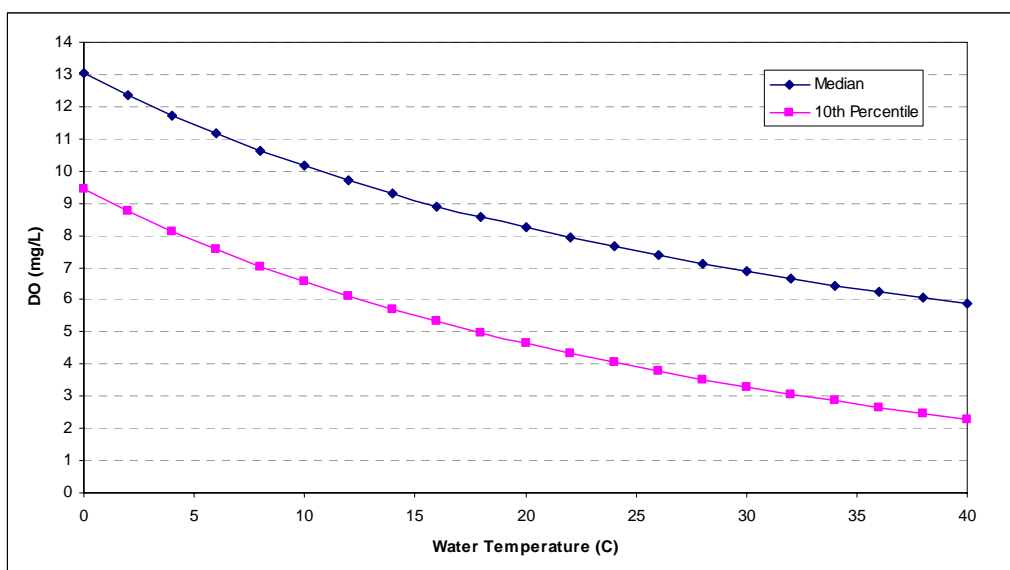


Figure 4.5. D.O. criterion curve based on 95% upper confidence limits on observed D.O. deficit, saltwater sites within the Terrebonne Basin, Louisiana.

These temperature-dependent results are generally consistent with the results obtained by direct evaluation of the D.O. statistics. The resulting D.O. criteria at a water temperature of 32.7 °C (95th percentile of the observed data), for example, are shown in Table 4.6. For all groups, the median is greater than the existing criterion, while the 10th percentile is close to the estimates based on direct evaluation of the summer DO data and provided in Table 4.4. As such, this alternative approach produces approximately the same site-specific D.O. criteria as the primary approach presented in Section 4.3.

Table 4.6. Example D.O. (mg/L) criteria based on D.O. deficit at 32.7 °C including results of two other criteria development approaches for the summer period.

Criteria Development Approach	Freshwater	Mixed Salinity	Saltwater
10 th percentile D.O. deficit	1.59	1.49	2.99
10 th percentile of the observed data	1.48	1.51	2.28
Upper 95% confidence limit on 10 th percentile	1.64	1.75	2.98

A weakness of the D.O. deficit approach is that it does not account for seasonal variability in the algal contribution to the D.O. balance. In the Terrebonne data, analysis in terms of D.O. deficit appears to reduce variability in results for the saltwater sites, but not for the freshwater and mixed salinity sites. For example, results for freshwater sites show a similar range for both daily mean D.O. and daily mean D.O. deficit, with both exhibiting seasonal patterns (Figure 4.6). Additionally, implementation of such an approach would be considerably more difficult than the more standard approach in that it would likely require adoption of temperature-dependent D.O. criteria. It is likely that the potential difficulties associated with implementing a D.O. deficit criteria (e.g., temperature dependence) and complexity of the resulting criteria which would require adoption of a continuum of D.O. criteria values over a range of expected temperatures has prevented this approach from being more attractive than D.O. criteria based on single concentrations. Although such an approach has been used to set wasteload allocations, it is not thought to have been applied anywhere as criteria.

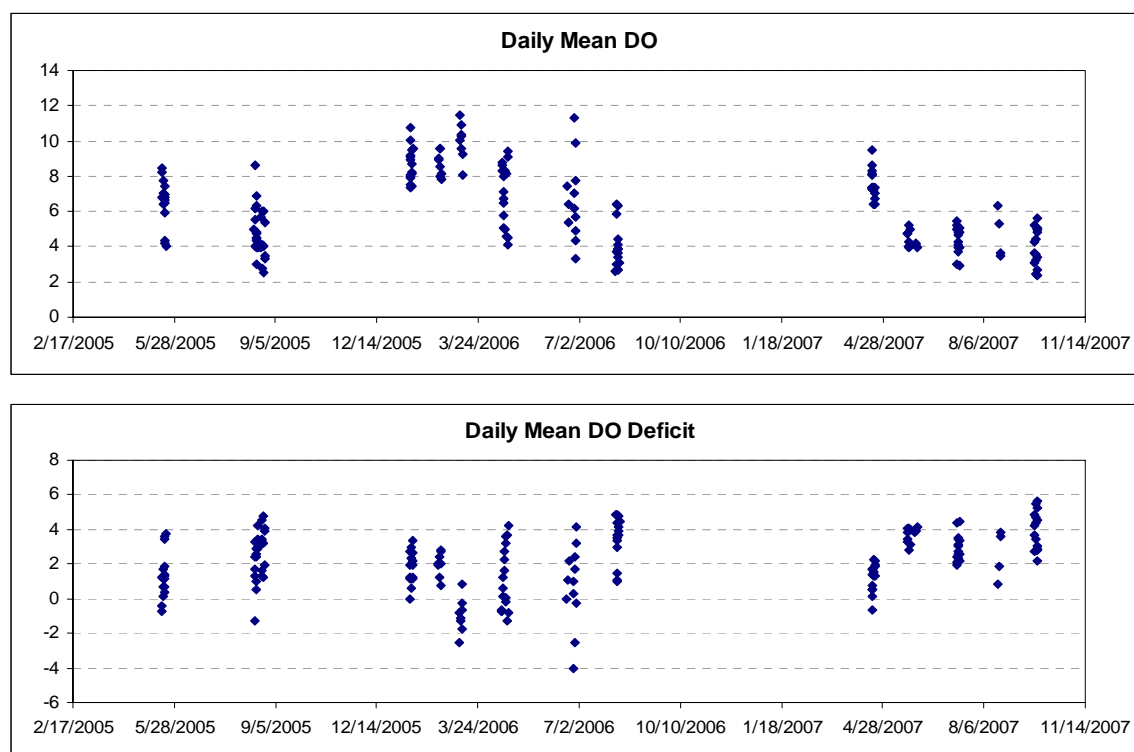


Figure 4.6. Summary of daily mean D.O. and daily mean D.O. deficit for all freshwater sites in the Terrebonne Basin, Louisiana.

4.4 Most Appropriate Method for Site-Specific D.O. Criteria Development

Based on the analyses conducted thus far, a reasonable approach may be to use the upper 95th percentile confidence limit of the 10th percentile of the observed D.O. data at reference sites as the winter seasonal criteria in the mixed salinity zone and summer seasonal (May through October) criteria (for each of the three areas) representative of natural background conditions of the Terrebonne Basin (Table 4.7). A less conservative method of applying site-specific criteria would be to simply apply the 10th percentile of the distribution of the D.O. as the site-specific criteria. Using this approach, the proposed site-specific summer D.O. criteria would be minimum (i.e., instantaneous) values of 1.6 mg/L for the freshwater area, 1.8 mg/L for the mixed salinity areas, and 3.0 for the saltwater areas. This approach would yield site-specific winter criteria of 4.71 mg/L in the freshwater areas and 3.16 mg/L in the mixed salinity areas (either no modification would be required of the 5.0 mg/L criteria in saltwater areas or this value could be revised based on analyses of natural background conditions). Other alternatives could be readily derived using different percentiles of the data (e.g., 5th percentile), different percent confidence limits (e.g., 90% confidence limits) or both combined, all of which would have some effect on the resulting criteria. It should also be noted that a criterion based on the 10th percentile of the data implies that approximately 10% of the samples for a given site class, on average, may have D.O. minima that are below the D.O. criterion and would be in non-compliance with the standard, even though it may be a natural occurrence.

Finally, the natural condition approach presented here is very dependent on the data used. Should more (or better quality) data become available for a given site class and reference conditions, the natural condition analysis may yield different D.O. criteria.

Table 4.7. Summary of potential site-specific daily minimum D.O. (mg/L) criteria generated using various analyses approaches for both the summer (May through October) and winter (November through April) periods in the Terrebonne Basin, Louisiana.

Site-specific Criteria Basis	Season	Freshwater	Mixed Salinity	Saltwater
10 th percentile of the observed data	Summer (May – October)	1.48	1.51	2.28
Upper 95% confidence limit on 10 th percentile	Summer (May – October)	1.64	1.75	2.98
10 th percentile of the observed data	Winter (November – April)	4.71	3.16	None
Upper 95% confidence limit on 10 th percentile	Winter (November – April)	None	3.76	None

5.0 Conclusions

Recent monitoring efforts within the Terrebonne Basin have indicated that 32 water bodies do not meet Louisiana's dissolved oxygen (D.O.) standards. There is concern that natural conditions within the Terrebonne such as high ambient water temperatures, slow moving and tidally influenced flow of water, and high concentrations of organic matter may cause water bodies within this Basin to exhibit D.O. values below state standards in the absence of anthropogenic stressors.

A recently completed study of conditions within the Terrebonne collected D.O. and related water quality parameters from 15 sites within three areas (freshwater, mixed salinity, and saltwater) of the Basin between August 2005 and 2006 (EPA 2007). This study also collected fish community data from each of these sites in August 2006. These data were augmented with D.O. and related water quality data collected by LDEQ at 9 sites in the same three areas of the Basin and fish community data collected at one additional site in the freshwater area.

The primary objective of this work was to use the assembled data to suggest scientifically defensible methods for derivation of D.O. criteria alternatives that are protective of aquatic life uses and reflective of natural conditions within the Terrebonne Basin. A secondary objective of this study was to evaluate the biological and water quality data to confirm that sampling sites included in this study and designated as "least impacted" by EPA, or representing reference conditions by LDEQ, are appropriate for use as natural conditions in evaluating D.O. conditions in this Basin.

Fish community values in the freshwater and mixed salinity areas were fairly similar while the composition of the saltwater communities was significantly different. Few meaningful relationships were determined to exist between calculated fish community metrics and various measures of D.O. Therefore, it was determined that there was no reason to conclude that any of the monitoring sites were not "least impacted" or reference conditions for purposes of developing D.O. criteria.

D.O. conditions were fairly similar in the freshwater and mixed salinity areas, while conditions in the saltwater area were significantly different. However, in all sites, the D.O. concentrations decreased markedly during the summer period (May through October) and was higher during the winter season (November through April). In spite of this trend the 10th percentile of the observed D.O. values was below applicable criteria in both the freshwater and mixed salinity zones. In fact, the concentration of D.O. was higher during the winter period than current D.O. standards in general.

For the winter period, the 10th percentile of the observed D.O. values was below applicable criteria for both freshwater (4.71 mg/L vs 5.0 mg/L) and mixed salinity sites (3.16 mg/L vs 4.0 mg/L). The 10th percentile value (5.59 mg/L) for the saltwater sites was greater than the existing minimum criterion (5.0 mg/L) for saltwater. Based on this analysis, there is potential need for site-specific D.O. criteria for both the freshwater and mixed salinity areas, however the saltwater areas of the Terrebonne Basin appear to be in compliance with existing D.O. criteria. Further

evaluation of these data revealed that the upper 95th percentile of the 10th percentile of D.O. observed at freshwater sites during the winter period exceeded the existing criteria (5.63 mg/L vs 5.0 mg/L), while the upper 95th percentile of the 10th percentile value fell below the existing criteria in mixed salinity areas (3.76 mg/L vs 4.0 mg/L). A site-specific D.O. criteria based upon the upper 95th percentile C.L. of the 10th percentile of observed D.O. concentrations appears pertinent for the mixed salinity zone (Table 5.1).

For the summer, the upper confidence limits on the 10th percentile are less than 5 mg/L for the freshwater and saltwater groups, and less than 4 mg/L for the mixed salinity group. Based on this analysis, the waterbodies are not meeting the existing criterion and site-specific revisions to the minimum criteria could address this situation for the summer period.

Potential site-specific criteria for the summer period were developed based on natural background conditions in the Terrebonne Basin using the upper 95th percent confidence limit of the 10th percentile of the D.O. distribution at these sites for both the summer and winter periods (Table 5.1).

Table 5.1. Potential daily minimum site-specific D.O. (mg/L) criteria for the summer (May through October) and winter (November through April) periods in the Terrebonne Basin, Louisiana.

Site-specific Criteria Basis	Season	Freshwater	Mixed Salinity	Saltwater
10 th percentile of the observed data	Summer (May – October)	1.48	1.51	2.28
Upper 95% confidence limit on 10 th percentile	Summer (May – October)	1.64	1.75	2.98
10 th percentile of the observed data	Winter (November – April)	4.71	3.16	None
Upper 95% confidence limit on 10 th percentile	Winter (November – April)	None	3.76	None

Alternative criteria were developed for the summer period using the D.O. deficit approach. Using this approach, the 10th percentile D.O. deficit during the summer period at these sites would be 1.59 mg/L (freshwater), 1.49 mg/L (mixed salinity), and 2.99 mg/L (saltwater).

Using these approaches, the site-specific D.O. criteria generated in this analysis during the summer period are all fairly similar and would result in site-specific criterion of between 1.5 and 1.6 mg/L for the freshwater area, from 1.5 to 1.8 mg/L for the mixed salinity areas, and between 2.3 and 3.0 mg/L for the saltwater areas. During the winter period the criteria would be 3.76 mg/L for the mixed salinity sites and would use the existing criteria for the freshwater and saltwater sites. Using the upper 95th percentile confidence limit of the 10th percentile of the D.O. distribution is a more conservative approach than simply using the 10th percentile of the D.O. distribution; however it may lead to a greater frequency of criteria exceedances than simply adopting the 10th percentile of the distribution. The D.O. deficit approach is attractive as it

accounts for temperature, however implementing such criteria would be more complex and is not known to have been done elsewhere.

6.0 Recommendations

6.1 Appropriate Site-Specific D.O. Criteria Development Approach

Of the three evaluated approaches to develop site-specific minimum D.O. criteria, development of criteria based on the upper 95th confidence limit of the 10th percentile of the observed D.O. values in the Terrebonne Basin may be most defensible. These criteria would be statistically based, appropriately conservative, and in keeping with the manner in which D.O. criteria have been adopted by Louisiana and other states.

This approach is also consistent with Louisiana's 305(b) use support assessment methodology. This methodology states that waterbodies are assessed as fully supporting designated uses if ≥ 90 percent of the samples meet the minimum D.O. criterion. This is consistent with the recommendation here of development of site-specific minimum D.O. criteria based on the upper 95th percent confidence limit of the 10th percentile of the natural background D.O. distribution. As such, criteria developed in this manner would not require any modification of existing LDEQ 305(b) methods.

The D.O. deficit approach was not selected as an appropriate approach for three reasons. D.O. criteria based on D.O. deficit rather than D.O. concentration are more complex because they require adoption of temperature-based criteria applicable over a wide range of expected temperature values rather than a single D.O. concentration. Also, monitoring for compliance with such criteria would require monitoring of not only D.O. concentration, but also temperature. Finally, D.O. deficit calculations have been used elsewhere in wasteload allocation work, but have not been adopted as criteria.

6.2 Next Steps

Based on our review of available fish and D.O. data resulting from monitoring efforts in the Terrebonne Basin, it has been determined that LDEQ has collected, and has access to, a much larger amount of relevant data. Although the efforts to gather and process those data as a part of the current project were limited by necessity, future efforts to evaluate D.O. criteria in this system would benefit from a more expansive effort to gather and incorporate these D.O. and fish data into the analysis. Such an effort would alleviate concerns regarding the limited sampling of fish communities (e.g., only a single sampling event conducted at 16 sites within the basin). Further, these data would allow a more in-depth evaluation of what biological communities and corresponding D.O. regimes are representative of least-impacted or reference conditions within the Basin. This knowledge would be exceedingly helpful in structuring future management strategies and decisions in this Basin. Finally, such an effort would be a significant step towards developing tiered aquatic life uses (TALU) for this Basin and possibly other similar areas in Louisiana (e.g., the Barataria Basin).

Additional next steps should include consideration of the appropriate monitoring methodology to evaluate compliance with existing and revised, site-specific criteria. Such consideration would include the manner in which samples are collected (e.g., periodic grab vs. continuous

monitoring), as well as the timing (both seasonal and daily) and frequency of sample collection. Also to be considered is a monitoring program to ensure that the adopted site-specific criteria are protective of designated uses in the Basin. Such a program could fairly easily be incorporated into a larger data synthesis effort similar to that discussed above.

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